Simple Bayesian Analysis to Model Pandemic Impacts at Knox County Schools

Technical Report

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Overview

Interrupted learning resulting from pandemic-related school closures has impacted student outcomes. From ACT to NAEP (National Assessment of Educational Progress) to NWEA map, multiple studies have shown dramatic losses in English/Language Arts, more dramatic losses in math, and the largest losses among students who started farthest behind their peers (Kuhfeld, 2022; Mumphrey, 2022; Skar, 2021; Wilburn, 2022). Analysis suggests that KCS schools are not immune to learning losses (Kerns, 2022).

Curriculum leaders developed strategies for dealing with interrupted learning when the Knox County Schools (KCS) closed in the Spring of 2020. KCS policymakers adopted an "acceleration" focus when schools reopened in the Fall of 2021. The acceleration strategy required all students to be taught grade-level material with targeted support for students who were missing pre-requisite skills. National-level qualitative research suggests that the success of the acceleration strategy was limited by absences (both staff and student), teacher capacity to fill in off-grade level gaps, and general staff burnout from a lack of administrative support (Destler, 2022; Pressley, 2022).

Dr. Charli Kerns of the Knox County Schools Department of Research, Evaluation, and Assessment (REA) conducted qualitative research at the behest of a KCS middle school teacher (Kerns, 2022). The teacher was executing the acceleration strategy, but classroom failure rates were increasing, and students appeared to have given up on schooling. Kerns applied a psychological capital framework to understand how students accessed resources during peri-pandemic learning opportunities. Kerns' findings suggest that struggling students could not access typical pathways to success because of learning gaps and holes in support networks. Kerns elaborates on the need for teachers to adapt to students' (new) to positively impact their resilience and hope.

Based on these findings, the quantitative arm of REA attempted to model pre- and peri-pandemic changes in student performance using Bayesian methods. The REA team hoped to qualify the magnitude of the changes in terms easily interpretable by district leaders. The approach is like researchers describing non-dimensional distribution shifts as months of learning (Student, 2022). The Bayesian analysis provides the probability that a school has seen a similarly performing cohort in the recent past. The results also allow us to make comparisons that are meaningful to operational managers. We can tell them that School X is (currently) encountering students with academic performance like School Y (in the past). The results have helped supervisors conceptualize the magnitude of the instructional shifts required at some schools.

Methodology

The quantitative researcher chose Bayesian analyses to describe the impacts of the pandemic on state test scores. The researcher used pre-pandemic state test data to build a baseline performance profile for each school. The researcher compared the first year of post-pandemic state test data (collected at the end of the 2020-2021 school year) to the pre-pandemic profiles of all schools in their respective grade band (elementary and middle). The resulting analysis provided a probability of the post-pandemic data coming from each school's pre-pandemic profile.

Baseline profiles were developed from state test results generated between 2016-2017 and 2018-2019. The researcher combined English Language Arts and math proficiency rates to calculate a "success rate" for each grade-level cohort. This procedure generated nine data points per school (three grade levels in elementary and middle schools in three years). The success rates were binned in five percentage point increments from 0% to 100% to generate a twenty-one interval histogram.

The researcher constructed the Bayesian analysis to answer the research question, "Has each school ever seen a cohort similar to how their entire population was performing?" The researcher calculated whole school "success rates" from 2020-2021 state test data. The analysis proceeded by identifying the histogram interval in which the 2020-2021 whole school success rate fell. We then calculated the likelihood that the observed 2020-2021 data came from each schools' pre-pandemic profile. The researcher assumed an uninformative prior. This means that we analyzed the 2020-2021 data as if it had equal probability of coming from any schools' pre-pandemic baseline.

The likelihood was calculated as the number of times the 2020-2021 interval occurred among nine historical data points for each school. Consider an example elementary school with a 2020-2021 "success rate" of 36% proficient. We find that interval (greater than or equal to 35% but less than 40%) occurred once among the nine pre-pandemic cohorts who attended the school. The likelihood of the data coming from its pre-pandemic baseline was 1/9 or 11.1%. The uninformative prior assumes that it is equally probable that the 2020-2021 data came from any of the forty-nine elementary schools included in the analysis. The prior probability is, therefore, 1/49 or 2.04%.

The posterior probability that the 2020-2021 data at school j was like a pre-pandemic cohort of any of the i elementary schools can be calculated as:

$$Posterior\ Probability_{SY2021,i} = \frac{Liklihood_j * Prior\ Probability_j}{\sum_i^{i+49} Liklihood * Prior\ Probability}$$

Note that middle schools will have larger posterior probabilities than elementary schools. The prior probability is higher for middle schools since there are fewer of them.

Results

The researcher aggregated posterior probabilities by school and plotted the information using bar charts. The plot has a bar for each comparison school to provide the posterior probability that the 2020-2021 performance was like pre-pandemic cohorts. An example plot for one de-identified KCS elementary school is in Figure 1.

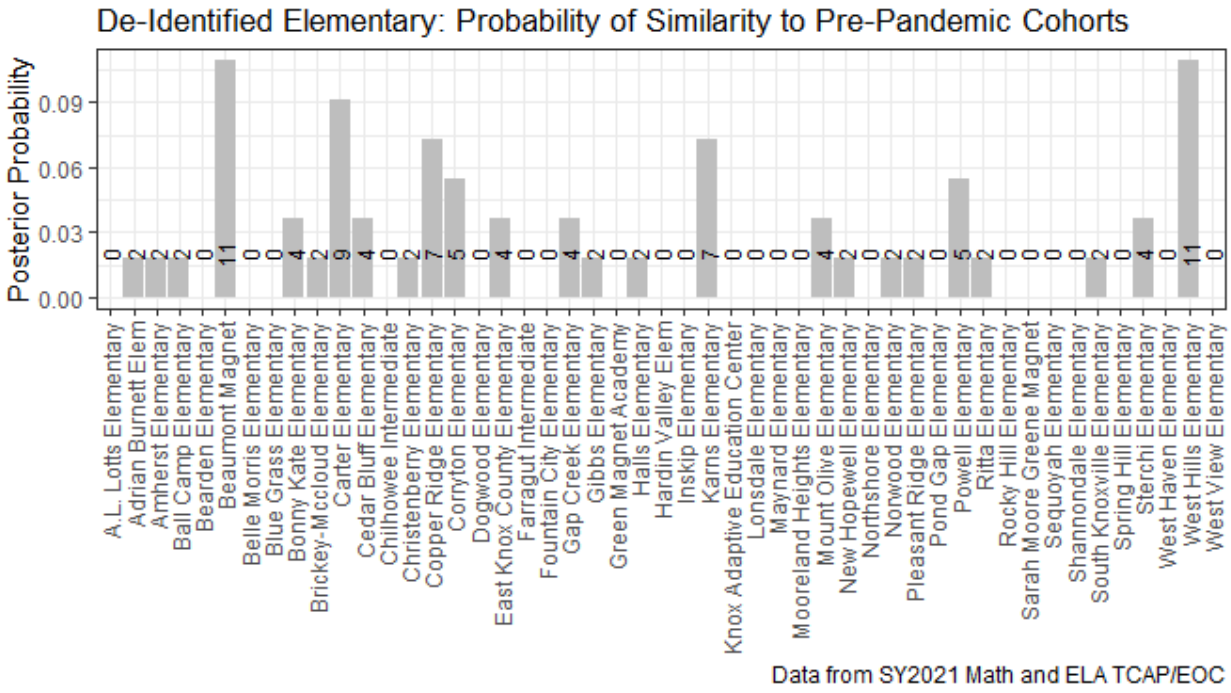

Figure 1: Example Bayesian Plot for a KCS Elementary School

Figure 1 shows that the 2020-2021 "success rate" at the de-identified elementary school was most like pre-pandemic cohorts of students at Beaumont Magnet and West Hills Elementary (11% posterior probability). There was no overlap (0% posterior probability) of the 2020-2021 success rate at the de-identified elementary school and twenty-four Knox County elementary schools. The researcher compiled plots like Figure 1 for each Knox County elementary and middle school.

The results of the analysis indicate:

- Six elementary and eight middle schools had no overlap (0% posterior probability) with their pre-pandemic (cohort-level) performance. In operational terms, these schools were likely teaching students with very different academic needs compared to past cohorts.
- Seven elementary schools and one middle school had a highest posterior probability match with their own school. In operational terms, these schools were likely teaching students with similar academic needs compared to past cohorts.

- The following descriptive statistics apply to the distribution of posterior probabilities:
    - Elementary Schools
        - N = 49
        - The median posterior probability that the schools' 2020-2021 data was from their own pre-pandemic distribution was 4.08%.
        - The maximum posterior probability that the schools' 2020-2021 data was from their own pre-pandemic distribution was 87.50%.
        - The mode posterior probability that the schools' 2020-2021 data was from their own pre-pandemic distribution was 3.85%.
    - Middle Schools
        - N = 16
        - The median posterior probability that the schools' 2020-2021 data was from their own pre-pandemic distribution was 3.57%.
        - The maximum posterior probability that the schools' 2020-2021 data was from their own pre-pandemic distribution was 100%.
        - The mode posterior probability that the schools' 2020-2021 data was from their own pre-pandemic distribution was 0.0%.

Conclusions & Considerations

REA generated plots (like Figure 1) for each KCS elementary and middle school. REA shared these with grade-level leadership to conceptualize changes in student outcomes during 2020-2021. Supervisors could conceptualize the academic gaps schools were facing by drawing on their experience with other schools. For example, a supervisor identified that School X's peri-pandemic success rate was comparable to School Y's pre-pandemic performance. These findings helped temper the supervisor's expectations at School X, especially if the pre-pandemic expectations regarding student outcomes were vastly different between the schools. It also helped supervisors think about the type of support that School X may now require. Programmatically, School X may now require the support School Y found helpful in the pre-pandemic era.

REA also provided school leaders with their Bayes plot during summer meetings. REA staff encouraged schools to find their best pre-pandemic match to build teacher networks through summer meetings. For example, School X may have a 0% posterior probability match with their own school. However, they may have a high posterior probability match with School Y. Leaders at School X were encouraged to gather ideas from School Y about addressing academic gaps.

There are potential issues with this type of analysis. REA was hopeful they could use the posterior probabilities from 2020-2021 as prior probabilities in a model using 2021-2022

state test results. The Supervisor of Research and Evaluation hoped to use the updated 2021-2022 posterior probabilities to monitor schools' returns to pre-pandemic baselines. However, the schools with a 0% posterior probability match with themselves would never show recovery. Literature suggests that priors can be adjusted when empirical evidence suggests the prior is inaccurate (Gelman, 2017). The Supervisor of Research and Evaluation does not have the experience to (confidently) adjust the prior probabilities.

Additionally, the analysis relies on binning performance data. The researcher did conduct sensitivity analyses. The researcher was concerned with how incremental changes in the interval width impacted the posterior probabilities. The 5% interval provided high stability in results while producing sensible posterior probability distributions. However, the results can be biased when schools and cohorts perform close to threshold values.

REA's goal with this analysis was to use quantitative methods to conceptualize changes in student outcomes. REA sought to communicate the impact COVID-19 has had on student outcomes by comparing peri-pandemic performance to pre-pandemic performance. Conceptualizing the magnitude of the changes in student outcomes to a school leader was a powerful tool. However, it is possible that there were unintended consequences to this approach. Specifically, comparing a school with lower performance to a pre-pandemic cohort can reinforce prejudices about the comparison schools. REA tried to counter preconceived notions by marketing the comparison school as a resource to be utilized rather than an entity to be pitied.

References

Destler, K., Hill, P. (2022). Back to School, but Not Caught up. Center on Reinventing Public Education. November 2022.

Donovan, T. M., & Mickey, R. M. (2019). Bayesian statistics for beginners: A step-by-step approach. Oxford University Press, USA.

Gelman, A., Simpson, D., & Betancourt, M. (2017). The prior can often only be understood in the context of the likelihood. Entropy, 19(10), 555.

Kerns, C. (2022). KCS Middle School Eighth-Grade Cohort School Year 2021-22 Focus Groups – Executive Summary. https://www.knoxschools.org/cms/lib/TN01917079/Centricity/Domain/1044/7.25.22%20KCS%20Middle%20School%208th%20Grade%20Focus%20Groups.docx.

Kuhfeld, M., Soland, J., & Lewis, K. (2022). Test score patterns across three COVID-19-impacted school years. EdWorkingPaper: 22-521, 37-62.

Mumphrey, C. (2022). ACT Test Scores Drop to Lowest in 30 years in Pandemic Slide, Associated Press.

Pressley, T. (2021). Factors Contributing to Teacher Burnout During COVID-19. Educational Researcher, 50(5), 325–327. https://doi.org/10.3102/0013189X211004138

Skar, G. B. U., Graham, S., & Huebner, A. (2021). Learning loss during the COVID-19 pandemic and the impact of emergency remote instruction on first grade students' writing: A natural experiment. Journal of Educational Psychology.

Student, S. R. (2022). Vertical Scales, Deceleration, and Empirical Benchmarks for Growth. Educational Researcher, 0013189X221105873.

Wilburn, G. Elias, J. (2022). Mathematics and Reading Scores of Fourth- and Eighth-Graders Declined in Most States During Pandemic, Nation's Report Card Shows. NAEP press release.